CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES
(GERERAL PROVISIONS AND BUILDINGS) -IS-1893-2016

IS-1893-Part-1-2016 By-Ishwar Singh Date-22.01.2018

1.1 **This standard deals with EQ hazards for EQ resistant of**
- i Buildings
- ii Liquid Retaining Structures
- iii Bridges
- iv Embankment and Retaining walls
- v Industrial and stack like structures
- vi Concrete, Masonry & Earth dams.

1.2 All Structures like need to be designed as per this code
- a Parking Structures
- b Security Cabins
- c Ancillary Structures

1.3 Temporary Elements need to be designed as per this code
- 1 Scaffolding
- 2 Temporary Excavations.

1.4 This Standard does not deal with construction features related to EQ buildings

1.5 Applicable to Critical Structures like
- i Nuclear Power Plants
- ii Petroleum Refinery Plants
- iii Large Dams.

3.1 Closely Spaced modes

Whose natural frequencies differ from each other by 10% or less of the lower frequency.

3.2 Critical Damping

Beyond which free vibration will not be oscillating.

3.3 Damping

i Effect of internal friction
Inelasticity of materials.
Slipping
Sliding etc in reducing amplitude of oscillation

ii Expressed as fraction of Critical Damping

3.4 Design acceleration spectrum

Refers to avg smoothened graph of max acceleration
Function of
Natural Frequency of natural period of oscillation.
for Specified Damping ratio at the base of SDOF system.

3.5 Design Horizontal Acceleration Coefficient.

Coefficient used for design of Structure.

3.6 Design Horizontal Force.

Horizontal seismic force used foe design

3.7 Ductility

Capacity of structure to under go large inelastic deformation with loss of stiffness or strength.

3.8 Epicentre

Point on earth surface Vertically above the origin of EQ

3.9 Floor Response Spectrum.

It is response spectrum of Time History of shaking generated at floor of structure When structure is subjected to given EQ motions at its base

3.10. Importance factor

Factor used to estimate design seismic force
Depends on

I Functional use
ii Hazardous consequences of its failure
iii Post EQ functional needs
iv Historical Value
v Economical importance.

3.11. Intensity of earthquake

Measure of strength of ground shaking at a place.
Indicated by MSK.

3.12. Liquefaction

Its is a state in Saturated **Cohesion less Soils**
Effective **Shear strength is reduced to negligible** for all engg purpose.
Pore pressure approaches to total confining pressure during EQ shaking.
Soil Tends to behave like a fluid mass.

3.14. Modal mass

Part of total seismic mass of structure.

Effective in natural mode k of oscillation during horizontal or vertical ground motions.

3.15. Modal Participation factor (Pk)in mode k of structure

Amount by which natural mode k contributes to Overall oscillation of structure during EQ vertical or horizontal EQ G motions

Depends on

Scaling used for defining mode shapes.

3.17. Mode Shape Coefficient

Spatial Deformation pattern of oscillation along the degree of freedom, when structure oscillating in its natural mode k

3.18. Natural period in mode k of oscillation.

Time taken (**in Seconds)** by the structure to complete one cycle of oscillation in its natural mode k of oscillation.

3.18.1. Fundamental Lateral Translational Natural Period (T1)

It is **Longest time in seconds** to complete one cycle of oscillation in its lateral translational mode. of oscillation in the considered direction.

3.19. Normal mode of Oscillation.

In which there are special undamped free oscillation in which
all points on the structure Oscillating Harmonically at the same frequency (period), such that all the points reach there
individual maximum responses simultaneously

3.20. Peak Ground Acceleration

Max Acceln of Ground in a given direction. (Refers to Horizontal)

3.21. Response reduction factor R

Factor by which Base Shear Indicated in Structure.
It is reduced to obtain the **DESIGN BASE SHEAR**

Depends on

Seismic damage performance of structure
Ductility
Brittle Deformation
Redundancy
Over strength inherent in the design process.

3.22. Response Spectrum

Its is max response of a Spectrum of idealized SDOF system of different natural periods but having same damping.

Refers to

Max absolute Acceleration.

Max relative Velocity.

Max relative Displacement.

3.23. Response Acceleration coefficient of a Structure.

Factor Denoting the normalized design accln spectrum value to be considered for design.

3.24. Seismic Mass of Floor

$$\frac{\text{Seismic Weight of floor}}{\text{Acc due to Gravity}}$$

3.25. Seismic Mass of Structure

$$\frac{\text{Seismic Weight of Structure}}{\text{Acc due to Gravity}}$$

3.26. Seismic Weight of floor

Sum of dead load of floor, columns, wall or any permanent element from the storey above and below. Finishes, Services, and specified amount of Imposed load.

3.27. Seismic Weight of Structure

Sum of seismic weights of all floors.

3.28. Seismic Zone factor (Z)

Value of peak ground acceleration considered by the code for design of structure. Located in each seismic Zone.

3.29. Time history analysis

Dynamic response of structure at each instant of time, when base is subjected to specific ground motion history.

4.2 Base

It is the level at which Inertia Forces Generated in the Building are considered to be transfer to the Ground through foundation.

It is considered at the bottom most basement level. For building resting on :-

i Pile foundation- aa the Top of pile cap

ii Raft :At the top of RAFT

iii Footing :- at the Top of Footing.

For Combined type of foundations :-

Base is considered as Bottom most of the bases of individual foundations.

4.3 Base dimension(d) :-

Dimension in meter- of the Base of the building along a direction of shaking..

4.4 Centre of Mass (CM) :-

Point in the floor of a building through which Inertia Force of the Floor is considered to act during EQ.

4.5 Centre of Resistant (CR) :-

a Single Storey

Point in the roof of a building through which when resultant internal resistant acts. **The Building Undergo**

i **Pure Translation** in the **Horizontal** direction

ii No Twist about Vertical axis passing through the CR

b Multi-storey Storey

It is the set of points on horizontal floors through which, when resultant incremental internal resistances across those floors act. **All the floors** of Building Undergo

i **Pure Translation** in the **Horizontal** direction

ii No Twist about Vertical axis passing through the CR

4.6 Eccentricity

a Design eccentricity

Value of eccentricity to be used for floor I in calculation of **torsion**

b Static eccentricity

Distance between Centre of mass and centre of resistance of floor i.

4.7 Design Seismic base shear (Vb)

Horizontal lateral force in the considered direction. That the structure shall be designed for.

4.8 Diaphragm.

Horizontal Structural system

i RCC Floor

ii Horizontal Bracing systems.

Which transmit lateral forces to vertical elements considered connected to it.

4.9 Height of floor (hi)

Difference in vertical elevation **base of building and top of floor i**

4.10. Height of Building (h)

Height-from **Base to top of roof level**

i **Excludes-basement storey height-when**

Basement walls are connected with ground floor slab

Basement walls are fitted between the building columns.

ii **Includes-basement storey height-when**

Basement walls are **not** connected with ground floor slab

Basement walls are **not** fitted between the building columns.

iii **In Step Back Building**

It shall be taken as average of heights of all steps from the base. Weighted with their corresponding area.

iv **The Building founded on hill slopes.**

Height of roof from the **top of the highest footing level** or pile cap level

4.11. Horizontal Bracing System

Horizontal Truss System- serve the **same function as diaphragm**

4.12. Joints

Portions of columns that are common to Beam/Braces & columns. Frame into columns

4.13. Lateral force Resisting System

All structural members that resist lateral inertia force.

4.14. Moment Resisting Frame

Assembly of BEAMs and COLUMNS that resist Induced and externally applied force.

4.15. Number of storey (n)

No of levels of building above the base at which mass is present.

i **Excludes-basement storey height-when**

Basement walls are connected with ground floor slab

Basement walls are fitted between the building columns.

4.16. Core Structural Walls, Perimeter columns, Outriggers and Belt Truss System.

System comprises of :-

Core of structural Walls

Perimeter Columns/Outrigger Columns -resists vertical and horizontal loads with :-

a Outriggers :- Structural walls connected to select perimeter columns by deep beams

b Belt Truss :-Outrigger columns connected by deep beam elements.

A structure with the Structural system has **enhanced lateral stiffness.**

Global lateral stiffness is sensitive to flexural stiffness/axial stiffness of outrigger elements.

4.17. Principle plan axes

Two mutually perpendicular horizontal directions in the plan of a building.

4.18. P-Δ Effect

It is Secondary effect on Shear force and bending moment of lateral force resisting elements.

4.19. RCC Structural wall

Designed to resist lateral force in its own plane.

i **Ordinary RC Structural walls**

Designed as per IS-456. **No ductile Detailing**

ii **Special RC Structural walls**

Designed and detailed as per IS-13920- **Ductile detailing**

4.20. Storey

Space between two adjacent floors.

4.20. 1 **Soft Storey**

Lateral stiffness < That in storey above.

Lateral stiffness :- Total Stiffness of all seismic force resisting elements.

4.20. 2 **Weak story**

Storey lateral strength (All elements)<that in storey above. **Other than Unreinforced masonry infill walls**

4.21. Storey Drift

Relative displacement between floors above or below the storey under consideration.

4.22. Storey Shear (Vi)

Sum of all Design lateral forces at all levels above the storey under consideration.

4.23. Storey lateral shear strength (Si)

Total lateral strength of all elements in the storey considered in a principal plan direction of the building.

4.24. Storey lateral Translational Stiffness (Ki)

Total lateral translational stiffness of all elements in the storey considered in a principal plan direction of the building.

4.25. RC Structural Wall Plan density (%)

Ratio of cross sectional area of walls at plinth level and plinth of building.

Expressed as % (percentage)

6 General principles

6.1.1 Ground motion-characteristics

i Intensity

ii Duration

iii Frequency :- **Depends on**

a Magnitude of earthquake

b Focal depth

c Epicentre distance

d Characteristics of the path through which seismic wave travel

e Soil Strata.

The predominant direction of ground vibration is usually Horizontal

Effect of vertical Vibration

Significant for overall stability analysis for Structures like :-

i Large spans

ii In which stability is criteria for design. Detrimental (Causing harm/Injury)-like

iii Prestressed horizontal structures

iv Cantilevered members-Beams, Girders and slabs.

v Gravity Structures

6.1.2 Response of a structure to Ground vibrations depends on :-

i Type of foundation

ii Material-form size and mode of construction of structure.

iii Duration and characteristics of ground motion.

6.1.3 **Actual force that appear on the structures during EQ are much higher than the Design forces specified in the Standard.**

Ductility :-Arising from inelastic material behaviour with appropriate design and detailing.
Over Strength :-Resulting from additional reserve strength in structures over

and Above the design strength are relied upon the for the deficit in actual and design lateral loads.
Earthquake design as per this standard relies on inelastic behaviour of structures.

Max ductility in structure is limited.

Structures Shall be designed for at least minimum lateral forces specified in this standard.

6.1.5 **Soil Structure Interaction**

Effect of flexibility on supporting soil-foundation system on the response of structure.
Soil Structure interaction may **not be considered** in the seismic analysis of structure **supported of Rock or Rock like material** at shallow depth.

6.1.6 **Equipment's of other system supported on various floor levels of a structure**

Equipment's of other system supported on various floor levels of a structure subjected to different motions at their support points.
It may be necessary to obtain the floor response spectra for design of equipment and its support. **IS-1893-part-IV**

6.1.7 **Addition to Existing Structures**

i An addition that is structurally **Independent** from existing structure-Shall be designed & constructed in accordance with **new seismic requirements for new structure**.

ii An addition that is structurally **connected** to existing structures shall be designed and constructed such that the **Entire structure** conform to the seismic forces resistance requirements of **new**

Following three conditions shall are complied

i Addition shall comply with the requirements of new structures

ii Addition shall not increase the seismic forces in any structural element of existing structure by more than 5%.

iii Addition shall not decrease the seismic resistance of any element of existing structure.

6.1.8 **Change in occupancy**

structure shall be reclassified to higher importance factor, shall conform to new structure requirements.

6.2 **Assumptions**

a EQ Ground motion are
Complex
Irregular
Several frequencies
Varying amplitude each lasting for a small duration.
Resonance of type as visualized under Steady State -**Sinusoidal excitations will not occur**

b EQ is **not** likely to **occur** simultaneously **with**
High Wind
Maximum Flood
Maximum Sea Waves

c The Value of elastic modulus of materials,
Where ever required will be taken for Static Analysis.
Unless more definite values are available for Dynamic conditions.

6.3 **Load combinations and permissible increase in Stresses**

6.3.2 Design Horizontal Earthquake Load.

a When lateral load resisting elements are **Oriented along Two mutually orthogonal Horizontal Directions**

Structure shall be designed for Full design load in one horizontal direction at a time.

Not in both directions simultaneously.

b When lateral load resisting elements are **Not Oriented along Two mutually orthogonal Horizontal Directions**

Full 100 % EQ in one direction + 30 % in other direction

i ±EQX±0.3ELy = ±100%ELX±30%ELY

ii ±0.3EQx±Ely = ±30%ELX±100%ELY

1 1.2(DL+LL±(EQx±0.3ELy))
1.2(DL+LL±(EQy±0.3ELx))

2 1.5(DL+LL±(EQx±0.3ELy))
1.5(DL+LL±(EQy±0.3ELx))

3 0.9*DL±1.5(EQx±0.3ELy))
0.9*DL±1.5(EQy±0.3ELx))

6.3.3 Design Vertical Earthquake Effects.

Shall be considered for following conditions :-

i Seismic zone- **IV** and **V**.

ii Structure is having Vertical and plan Irregularity.

iii Structure is resting of **Soft Soil.**

iv Bridges

v Structure has **long spans**

vi Structure has **large horizontal Overhang** of structural members or sub system

6.3.5 Increase in Net pressure on soils in design of Foundations

6.3.5.2 In design of foundations Unfactored loads shall be combined, while assessing the bearing pressure in soils.

Table-01

Increase in Net pressure depends on :-

i Type of foundation

ii Type of soil- **4-types** of soils types.

% increase		
	Rock or Hard Soils	50
	Medium or stiff soils	25
	Soft Soils	0

iii In **soft soils no increase shall be applied** because the settlements cannot be restricted by increasing bearing pressure.

6.3.5.3 If Soil Consists of

Submerged loos sands

Soils falling under classification SP. With corrected **SPT values N, SP=**poorly graded sands.

SPT values N<15 in zone :- III, IV & V

SPT values N<10 in zone :- II

The EQ ground motion may cause

Liquefaction

Excessive total & differential settlements.

These sites should be **avoided** for **new structures** and **Important Projects.**

Precautions

i Settlements need to be investigated

ii Appropriate method of Compaction or stabilization to achieve N values.

iii Deep pile foundation may be adopted & anchored at depths well below underlying soil layers. Which are likely to liquefy or undergo excessive settlements.

iv Piles should be designed for lateral loads neglecting lateral resistance of soil layers which are liable to liquefy

Marine clay layers & sensitive clay layers

Are known to liquefy,

Undergo excessive settlements or collapse.

Low shear strength- such soil need special treatment as per site condition.

6.4.2 Design Acceleration Spectrum.

Horizontal seismic coefficient Ah determined by

Ah= ((Z/2)x(Sa/g))/(R/I)

Minimum Value of Importance factor shall be :-

i Critical and lifeline Structures = 1.5

ii For business continuity structures = 1.2

iii Rest all = 1.0

Design Acceleration Coefficient for different soil

	Static analysis		Dynamic Analysis	
Rocky/Hard soil sites			1+15 T	T < 0.10 s
	2.5	0 < T < 0.40 s	2.5	0.10s < T < 0.40s
	1/T	0.40s < T < 4.0s	1/T	0.40s < T < 4.0s
	0.25	T > 4.0s	0.25	T > 4.0s
Medium stiff soil sites			1+15 T	T < 0.10 s
	2.5	0 < T < 0.55s	2.5	0.10s < T < 0.55s
	1.36/T	0.55 < T < 4.0s	1.36/T	0.55s < T < 4.0s
	0.34	T > 4.0s	0.34	T > 4.0s
Soft soil sites			1+15 T	T < 0.10 s
	2.5	0 < T < 0.67s	2.5	0.10s < T < 0.67s
	1.67/T	0.67 < T < 4.0s	1.67/T	0.67s < T < 4.0s
	0.42	T > 4.0s	0.42	T > 4.0s

6.4.2.1 Type of soil Table-2

			% increase in SBC	N-value
i	Soil type-I-A	Rock or Hard Soils	50	N>10
ii	Soil type-II-B	Medium or stiff soils	25	N-10-30.
iii	Soil type-III-C	Soft Soils	0	N<10
iv	Soil type-D	Require site specific Study	Unstable, Collapsible, Liquefiable	

The value of N to be used shall be weighted average of N of soil layers from the Existing ground level to 30 m below the existing ground level.

The N-values for individual layers shall be the Corrected values

Only corrected value of N-shall be used

Minimum corrected field value of N-shall be

Zone	Depth Below Ground	N- Value	
III, IV	≤ 5m	15	For depth values between 5 to 10 m linear interpolation shall be recommended
V	≥ 10m	25	
II	≤ 5m	10	
	≥ 10m	20	

6.4.2.1 Seismic Zone Factor-Table-3

	II	III	IV	V
Z	0.1	0.16	0.24	0.36

6.4.3 Effect of EQ can be considered Two ways

1) Equivalent static method — For Regular structures with time period<0.4 s

2) Dynamic analysis method

Dynamic analysis method

i Response Spectrum Method — Adopted by IS-1893-2016

ii Modal Time History

iii Time History Method Adopted by IS-1893-2016

6.4.3.1 For Structural Analysis moment on Inertia shall be taken

a For Columns-in RC and Masonry Structures- 70 % of I gross

In Beams 35 % of I gross

b Steel Structures- I gross for both beam and columns

6.4.5 For Under Ground Structures and building whose base is >30 m

Ah = half the value =0.5 Ah

This reduced value shall be used only for estimating inertia effects due to masses below ground.

Inertia effect above ground shall be based on unreduced value.

For Structures and foundation between GL and 30m

Linear interpolation between Ah and 0.5 Ah shall be done.

6.4.6 Design Acceleration Spectrum. Or Vertical motions

Vertical seismic coefficient Av determined by

$$Av = \frac{2 \times Z}{3 \times 2} \; 2.5 \; \frac{I}{R}$$ **For Buildings**

$$\frac{2 \times Z}{3 \times 2} \; 2.5 \; \frac{I}{R}$$ **For Liquid Retaining Tanks**

$$\frac{2 \times Z}{3 \times 2} \; \frac{Sa}{g} \; \frac{I}{R}$$ **For Bridges**

$$\frac{2 \times Z}{3 \times 2} \; \frac{Sa}{g} \; \frac{I}{R}$$ **For Industrial Structures.**

Sa/g Shall be based on Natural period corresponding to 1st vertical mode of oscillation.

6.4.7 When design spectrum is developed specific to a project site -same may be used for design, but shall not be less than given in code.

7.0 Buildings

4-Attributes of an EQR buildings

i Robust Structural configuration-Strong & healthy

ii At least minimum elastic lateral stiffness

iii At least minimum lateral strength.

iv Adequate ductility.

7.1 Regular & Irregular configurations.

Simple regular geometry

Uniformly Distributed mass

Uniformly Distributed Stiffness in plan and elevation.

1) Torsional Irregularity

a Well proportioned building does not twist about its Vertical axis.

i **Vertical Elements** :-if balanced in plan according to distribution of mass in plan

ii **Floor Slabs** :-Are **stiff** in their own plan when **aspect ration<3**

Torsional Irregular buildings

i **Max horizontal displacement** of one end of any floor in the direction of lateral force
>1.5x times min horizontal displacement at far end of same floor.
Range 1.5-2.0- Building configuration shall be revised

ii **Natural period**- corresponding to fundamental torsional mode of oscillation
> than those 1st 2 translational modes along each principal directions.

a) Range 1.5-2.0- Building configuration shall be revised to ensure natural period less then 1st two translational modes

b)-1.5 - 2.0 then- **3D- Dynamic-analysis method shall be adopted.**

iii >2.0- Building configuration shall be revised.

2) Re-entrant corners.

When structural configuration in plan has a projection >15 % of its over all plan dimension.

Solution- 3D Dynamic analysis method shall be adopted

3) Floor Slabs Excessive Cut-outs or Openings.

Opening in slab results-in flexible diaphragm.

Flexible diaphragm- Lateral forces is not shared by frame or vertical members in proportion to their lateral translational stiffness.

a **Discontinuity in plan when**

Floor slabs having cut-outs or opening >**50% of full area of floor slab**

b **Discontinuity in their plan stiffness**

If area of geometric cut-out

Less Than equal to 50% -Floor slab shall be taken as **Rigid or Flexible** based on location and size of cut-out

Greater than 50% -**Flexible floor slab**

4)Out of plane Offset in Vertical Elements.

Cause discontinuity & Detour in load path, when structural walls or frame are moved out of plan in any storey along the height of building

i **For buildings in Zone-II :-**

For design special literature shall be referred.

i **For buildings in Zone-III,IV & V :-**

a Lateral drift shall be <0.2 % in the storey having offset & storeys below.

b Special literature shall be referred for removing out of plan offset.

5) Non parallel Lateral Force System.

When lateral force resisting system not oriented along two plan directions-**Building under go complex**

i **EQ behaviour..**

ii Shall be analysed for special load combinations.

6) Vertical Irregularity-Table-6

a **Stiffness Irregularity (Soft Storey)**

Storey whose lateral stiffness less than that storey above.

Structural Plan Density (SPD)

i When Unreinforced masonry infill are used

ii When SPD of masonry infill > 20%

iii Effect of URM infill shall be considered by modelling in analysis.

a) Bare Frame

b) Frame with URM infill- using 3-d modelling

In buildings Designed considering URM infills

Inter-Storey drift shall be limited to 0.2% **in the storey** and also in **storey below.**

b **Mass Irregularity.**

When Seismic weight of any floor **>150%** of that **floor above**

Mass Irregularity in **ZONE-III,IV, & V-** EQ effect shall be estimated by **Dynamic Analysis Method**

c **Vertical Geometric Irregularity.**

When Horizontal dimension of the lateral force resisting system **>125%** of storey **below.**

Vertical Geometric Irregularity. in **ZONE-III,IV, & V-** EQ effect shall be estimated by **Dynamic Analysis Method**

d **In-Plan discontinuity in vertical Elements resisting lateral forces.**

When in plane offset **>20%** of the **plan length**

For buildings in Zone-II :-

Lateral drift shall e=be limited of **0.2 % of building height**

For buildings in Zone-III,IV & V :-

In plan discontinuity **NOT PERMITTED**

e Strength Irregularity- (Weak Storey)

Lateral strength less than the S**torey Above**

f Floating or Stubbed Columns

Such columns cause concentrated damage in the structure.

This feature is **Undesirable** and should be **Avoided if it is part of Supporting the primary lateral load resisting system.**

g Irregular mode of Oscillation in Two Principal directions

Stiffness of Beams
Columns
Braces
Structural walls -determine the lateral stiffness of building.
In each principal direction.

i If **1st 3 modes**- contribute **less than 65 % mass participation factor** in each principal direction. In **Zone -II and III, IV & V**

ii Fundamental lateral natural periods of building in two principal plan directions closer to each other by **10% of the larger value- Zone-IV & V**

7.2.1 Lateral Force

Shall be designed for base shear Vb

Vb = AhxW

7.2.2 Minimum Design Lateral Force

Buildings shall have lateral load resisting system capable of resisting horizontal forces not less than

Table-7

Minimum Design EQ Horizontal lateral forces.

	Zone	p %
i	II	0.7
ii	III	1.1
iii	IV	1.6
iv	V	2.4

7.2.3 Importance Factor

a		I
Important Services		1.5
Community Buildings		1.5
1	Critical Governance Buildings.	1.5
2	Schools	1.5
3	Signature Buildings	1.5
4	Monument Buildings	1.5
Life line and emergency		1.5
5	Hospitals	1.5
6	Telephone Exchange	1.5
7	Television Station	1.5
8	Radio Station	1.5
9	Bus Station	1.5
10	Metro Rail Buildings	1.5
11	Metro Rail Station	1.5
12	Railway Station	1.5
13	Food Storage Buildings- Warehouse	1.5
14	Fuel Station	1.5
15	Power Station	1.5

	16	Fire Station.	1.5
		Large Community Buildings	1.5
	17	Cinema Hall	1.5
	18	Shopping Mall	1.5
	19	Assembly Hall	1.5
	20	Subway Station	1.5
b		**Residential & Commercial Buildings other than above** **Occupancy >200 persons**	**1.2**
c		All Other Buildings	1.0

Note-1:- Owner and design Engineer may choose the value of importance factor more than above

Note-2- Buildings with **mixed occupancy**-where difference I- factor applicable-**larger importance factor of two shall be used**

7.2.4 Damping Ratio

The Value shall be taken as 5 % of critical damping.

7.2.5 Design Acceleration Spectrum

Sa/g- corresponding to 5 % damping

Depends on :-

Type of soil

Peak Ground Acceleration.

Natural Period of Structure.

Material of construction.

7.2.6 Response Reduction Factor

a Influences the non-linear behaviour of buildings during strong EQ

b Accounts for inherent system ductility, Redundancy and Over strength.

7.2.7 Dual System

Consists of

a Moment resisting frame and Structural Walls.

b Moment resisting frame- designed to resist independently **at least 25 %** of base Shear.

Table-9-Response reduction factor

			Allowable zone	
i		**Moment Frame Systems**		
	a	RC Buildings with Ordinary Moment Resisting Frame (OMRF)	II	3
	b	RC Buildings with Special Moment –Resisting Frame (SMRF)	All	5
	c	Steel buildings with Ordinary Moment Resisting Frame (OMRF)1	II	3
	d	Steel Buildings with Special Moment Resisting Frame (SMRF)	All	5
ii		**Braced Frame Systems**		
	a	Buildings with Ordinary Braced Frame having Concentric Braces	All	4
	b	Buildings with Special Braced Frame having Concentric Braces	All	4.5
	c	Buildings with Special Braced Frame having Eccentric Braces	All	5
iii		**Braced Frame Systems**		
	a	Buildings with Ordinary Braced Frame having Concentric Braces	All	4
	b	Buildings with Special Braced Frame having Concentric Braces	All	4.5
	c	Buildings with Special Braced Frame having Eccentric Braces	All	5
iv		**Structural Wall Systems**		
a		**Load Bearing Masonry Buildings**		

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	1	Unreinforced Masonry (designed as per IS 1905) without horizontal RC Seismic Bands.	II	1.5
	2	Unreinforced Masonry (designed as per IS 1905) with horizontal RC Seismic Bands.	ALL	2
	3	Reinforced Masonry [refer SP 7 (Part 6) Section 4]	ALL	3
	4	Confined Masonry	ALL	3
b		Buildings with Ordinary RC Structural Walls	II	3
c		Buildings with Ductile RC Structural Walls	ALL	4
v	**Dual Systems**			
	a	Buildings with Ordinary RC Structural Walls and RC OMRFs1	II	3
	b	Buildings with Ordinary RC Structural Walls and RC SMRFs1	II	4
	c	Buildings with Ductile RC Structural Walls with RC OMRFs1	II	4
	d	Buildings with Ductile RC Structural Walls with RC SMRFs	ALL	5
vi	**Flat Slab –Structural Wall Systems**			
	i	**Punching shear be avoided**		
	ii	**Lateral drift at the roof under design lateral force shall not exceed 0.1 %**		
	a	RC Building with (a)Ductile RC Structural Walls (which are designed to resist 100% of the design lateral force).	ALL	3
	b	Perimeter RC SMRFs (which are designed to independency resist 25% of the design lateral force),and	ALL	3
	c	Preferable an outrigger and belt truss system connecting the core Ductile RC Structural Walls and the perimeter RC SMRFS1	II	3

7.3.2 Design Imposed load for EQ calculations

i Live load on Roof need not to be considered.

ii Weight of **equipment and other permanent fixed facilit**y should be considered and **No reduction of Live Load**

Table-10

% imposed load considered -for Seismic weight		
	Imposed load on floors (KN/m2)	% LL
a	Up to including 3.0	25
b	Above 3.0	50

Table-7

Zone	p %
II	0.7
III	1.1
IV	1.6
V	2.4

7.3.4 a For more accurate assessed load value the Table -10 can be replaced to Table 7

Loads other than above -**Snow & permanent equipment**-shall be considered appropriately

7.3.5 b In regions of **Heavy Snow and Sand storms** exceeding **1.5 KN/m2**

20 % of snow or sand load shall be included in estimation of Seismic weight.

7.3.6 c Buildings having Interior partition walls

Weight of these partition shall be included in seismic weight calculations.

The minimum value shall be 0.5 KN/m2 or as per IS-875- **Take maximum value**

7.6 Equivalent Static Method

This method applicable for Regular Buildings with height Less than 15m in Zone-II

7.6.2 Approximate Fundamental Translational Natural Period-Ta

a Bare MRF Building- Without Masonry Infill

h-Height of building in m

Ta =	RC-Moment Resisting Frame =	0.075 $xh^{0.75}$

Ta =	RC-Steel- **Composite** MRF =	0.080 $xh^{0.75}$

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Ta =	Steel- MRF =	$0.085\ xh^{0.75}$

h = **Excludes-height**

i When basement storey walls connected to ground floor deck

ii When basement storey walls fitted between buildings columns.

Includes-height

i When basement storey walls **not** connected to ground floor deck

ii When basement storey walls **not** fitted between buildings columns.

b Building with RC Structural Walls

RC-Moment Resisting Frame =	$0.075\ xh^{0.75}$	≥ 0.09h
	√Aw	√d

Aw-Total Effective area of wall in 1st storey.

d- Base dimension of building at plinth level along considered direction

$$A_w = \sum_{i=1}^{N_w}\left[A_{wi}\left\{0.2+\left(\frac{L_{wi}}{h}\right)^2\right\}\right]$$

Aw- Effective cross sectional area of wall -in 1st storey in m2

Lwi- Length of structural wall in 1st storey in considered direction in m.

Mw- No of walls in considered direction.

Lwi/h= Shall not exceed =0.9

c All Other buildings

Ta = $\dfrac{0.09h}{\sqrt{d}}$

7.6.4 Diaphragm

a Flexible Diaphragm

Δ1 =Minimum Displacement a end-1

Δ2 =Maximum Displacement a end-2

$\Delta avg = \dfrac{\Delta 1+\Delta 1}{2}$

Δmiddle =	> 1.2x Δ avg

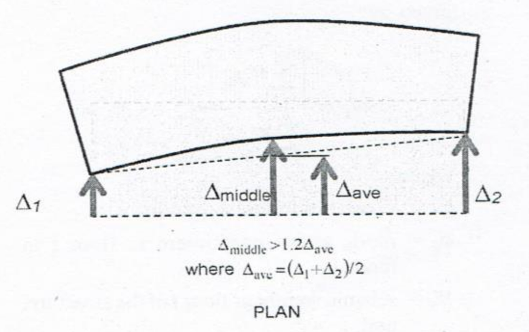


FIG. 6 DEFINITION OF FLEXIBLE FLOOR DIAPHRAGM

b Rigid Diaphragm

i Monolithic Slab-Beam Floors.

ii Prefabricated

iii Precast Elements-with RCC screed 50mm of floor & 75mmon roofs with 6mm@150mm c/c as topping

iv Plan Aspect ration less than 3

7.6 Dynamic Analysis Method

7.71 Linear Dynamic Analysis shall be carried out for all Irregular Building lower than 15m in Zone-II.

a Time history Method

b Response Spectrum Method

7.73 Vb -Estimated shall be less than Vb'-Calculated using fundamental period.

i When Vb<Vb'

Member Stress resultants

Storey Shear

Base reaction

Shall be multiplied by = $\dfrac{Vb'}{Vb}$ **For mutual perpendicular plan directions.**

i $\frac{V_{bx}'}{V_{bx}'}$ For X-direction

ii $\frac{V_{by}'}{V_{by}'}$ For Y-direction

ii For Vertical directions Z

Multiplying factor shall be Max of above two.

7.7.4 Time History Method

Based on- Appropriate Ground Motion-

Preferably compatible with design acceleration spectrum

7.7.5 Response Spectrum

Based on- Design Acceleration Spectrum or

Based on- Site Specific design acceleration spectrum.

7.7.5.2 No of modes to be considered

i Such that the Sum of total of model masses of these modes considered is at least 90% of total seismic mass.

ii If modes with natural frequency >33 Hz are to considered

Model combination shall be carried of for modes with natural frequency <33Hz.

iii If modes with natural frequency >33 Hz shall be included by missing mass correction procedure.

iv Designer may use cut off frequency other than 33Hz

7.8 Torsion

7.8.1 i Twisting about Vertical axis of the building, arising due to eccentricity between Centre of mass and centre of resistance at floor levels.

ii The **design forces Vb shall be applied at the displaced centre of mass** so as to cause displaced centre of mass and centre of resistance.

7.8.2 Design Eccentricity-edi

edi =	1.5 esi+0.05bi	
	esi-0.05bi	Which ever is more.

esi = Static eccentricity at ith floor.

esi = Distance between centre of mass - Centre of resistance.

bi = Floor plan dimension of floor i- perpendicular to the direction of force.

1.5- Dynamic amplication factor.

0.5bi - Represents- extent of accidental eccentricity.

Don’t use 1.5- while performing Time History Analysis.

7.9 RC Frame with unreinforced masonry infill.

7.9.2 In plan stiffness and strength of masonry infill wall

7.9.2.1 Modulus of elasticity of masonry *Em* = 550 *fm*

fm = Compressive strength of masonry prism-IS-1905

$$E_m = 550\,f_m$$

$$f_m = 0.433\,f_b^{\,0.64}\,f_{mo}^{\,0.36}$$

fb = **Compressive** strength of **Brick** in Mpa

fmo = **Compressive** strength of **Mortar** in Mpa

7.9.2.2 URM infill walls shall be modelled using

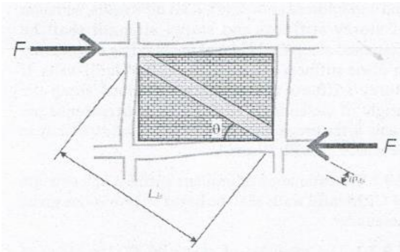
Equivalent Diagonal Strut.

a End of diagonal shall be considered to be pin jointed to RC frame.

b For URM infill walls **without any opening**

Width of equivalent diagonal Strut-Wds

$$W_{ds} = 0.175\,\alpha_h^{-0.4}\,L_{ds} \qquad \alpha_h = h\left(\sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_f I_c h}}\right)$$



Em = Modulus of elasticity of URM infill
Ef = Modulus of elasticity of MRF
Ic = MOI of adjoining column.
t = Thickness of infill
θ = Angle of diagonal with horizontal.

C For URM infill walls **with opening**
No reduction in strut width is required.

d Thickness of equivalent diagonal strut = Thickness t of original URM infill wall provided.

$\frac{h}{t} < 12$ $\frac{l}{t} < 12$

Where h=clear height of URM infill wall (Top beam & bottom floor slab)
l = Clear length between vertical RCC elements-Columns, Wall.

7.10. RC Frame Building with Open Storeys

Discontinuity of URM infill walls or structural walls at any level.
Are also Known as **Flexible or Weak storey**
In such buildings suitable measure shall be adopted

i **Provide RC Structural Walls-**
- a Shall be founded of properly designed foundation.
- b Continuous Over full height of building.
- c Connected preferable to moment resisting frame of building.

ii **Braced Frames,**

7.10.3 RC Structural Walls-

Shall be -Designed that walls does **not have**
- a Additional Torsional Irregularity
- b Lateral Stiffness in Open Storey < 80% of that in Storey Above
- c Lateral Strength in Open Storey < 90% of that in Storey Above

7.10.4 RC Structural Walls-Plan Density
- i At least 2 % along each principal direction. **In Zone-III,IV & V**
- ii These walls shall be well distributed in the plan along each plan direction.
- iii This measure **can be adopted** in **Regular** buildings -**without** open storey
- iv RC Structural walls in **Zone-III,IV and V**- shall be **designed & Detailed as per IS-13920**

7.11.1 Storey Drift Limitation

Storey Drift in any storey shall not exceed **0.004 x Storey height.**
Under the action of design base shear.

i $\text{Storey Drift} = \frac{\text{Storey Height}}{250}$

ii Partial safety factor for all Loads =1

7.11.1.2 Displacements

Displacements obtained from Dynamic analysis **shall not be scaled**

7.11.2 Deformation capability of Non- Seismic- Members.

For Buildings located in Zone-III,IV & V
Monolithically connected -members do not loose their Vertical Load carrying capacity under induced net stress resultant.
Including Bending moment and Shear Forces resulting from storey deformation.
.= Rx Storey Displacements.
Storey Displacements = 0.004 x Storey Height
R = Response reduction factor.

7.11.3 Separation Between Adjacent Units.

Buildings with separation joint between them

To avoid pounding when the oscillated towards each other.

Separation =	Rx(Δ1+xΔ2)

R-Response reduction factor

When Floor are at Same level.

Separation = R1xΔ1+R2xΔ2

R1 &R2- Response reduction factor for Building-1 &2

Δ1 and Δ2= Displacement of building 1 &2

7.12.1 Foundations

When-N-corrected < 10 (Soft Soils) in any Zone

i Isolated footing without tie beams — Not Permitted

ii Unreinforced Strip Foundation — Not Permitted

iii Foundation Vulnerable to Significant Settlements- Shall be avoided in Zones-III,IV & V

iv Individual Spread **Footings or Pile Caps**- Shall be connected with Ties, except those supported on Rock.- **-In Zone-IV and V**

Ties as per -IS-4326-5.3.4.1

a Where ties are used, their sections shall be designed to carry in tension as well as in compression, an axial load not less than the earthquake force acting on the heavier of the columns connected,

b	but the sections shall not be less than **200 mm × 200** mm	**SIZE**
c	With **M15** concrete reinforced	**Concrete Grade**
d	With **4 bars of 12** mm dia plain **mild steel** bars or	**R-F**
	10 mm dia **high strength deformed** bars,one at each corner,	**R-F**
e	Bound by 6 mm dia mild steel stirrups	**Ring**
f	**Not more** than **150** mm apart.	**Ring-Spacing**

v All tie shall be capable of carrying-In tension & In-compression, An axial force=Ah*P/4

$$\text{Min-Compression/Tension/Axial Force} = \frac{Ah*P}{4}$$

P=Larger of column or pile cap load

vi **Minimum Load** = 5 % of larger of column or pile cap loads

vii Pile shall be designed and Constructed to withstand maximum curvature imposed by earthquake Load.

7.12.2 Cantilever Projections

a Vertical Projections-Attached to Building above roof

i Small Sized Facilities -like

1 Towers

2 Tanks

3 Parapets

4 Smoke Stake/Chimney

ii **Shall be designed for Stability =5 x Horizontal seismic coefficient(Ah)**

iii Weight of these elements shall be lumped with the roof weight.

b Horizontal Projections-

1 Cantilever at Porch Level.

2 Bracket

3 Cornices

4 Balcony

Shall be designed for Stability =5 x Vertical seismic coefficient(Av)

Note-The increased design force are only for Components ont for main Structure

7.12.3 Compound Walls.

Shall be designed for Horizontal Seismic coefficient =1.25 x Ah

Ah is calculated using -

I =	1
R =	1
Sa/g	2.5

7.12.4 Connection Between Parts.

i Small Items or objects tied to the buildings shall be capable of transmitting force induced in them

ii Minimum = 0.05*Weight of Total DL+LL Reactions

ANNEX D MSK 1964 INTENSITY SCALE

D-1-a Type of structure

1 Type-A

- i Building- in field Stone
- ii Rural Structure
- iii Unburnt Brick House
- iv Clay House

2 Type-B

- i Ordinary Brick Buildings
- ii Large Block Buildings
- iii Prefabricated type
- iv Half Timbered Structures
- v Natural Hewn Stone Buildings

3 Type-C

- i RCC
- ii Well Build Wooded Structures

b Quantity

Single, Few	About 5%
Many	About 50%
Most	About 75%

c Classification of Damage

i **Grade-1** **Slight damage**
Fine Cracks in plaster
Falls of small pieces of plaster.

ii **Grade-2** **Moderate Damage**
Small Cracks in Walls
Fall of fairly large piece of plaster.
Pantile Slip off
Cracks in chimney parts and fall down

iii **Grade-3** **Heavy Damage**
Large and deep cracks in walls
Fall of chimney

iv **Grade-4** **Destruction**
Gap in walls
Part of building collapse.
separate part of building loose their cohesion
Inner Wall Collapse.

vi **Grade-5** **Total Damage**

Total collapse of buildings.

D-2 MSK Intensity Scale

Following letters used- I,ii and iii

Intensity Scale - I to XII

Persons and Surrounding	i
Structures of all kinds	ii
Nature	iii

I Not Noticeable

i Vibration below the limits of sensibility
Tremor- detected & recorded by Seismograph.

ii

iii

II Scarcely Noticeable- Very Slight

Vibration felt to individual people at rest in houses
In upper floors of buildings.

ii

iii

III Weak-Partially observed

EQ felt indoor by few peoples
Slight swinging of hanging objects.
Vibration felt like passing of **Light Truck**

ii

iii

IV Largely Observed

i Felt indoor by many people
Outdoor by few people
Here and there people awake.
No one frighten
Vibration felt like passing of **Heavy Truck**
Windows, Doors and Dishes- rattle (Make short Sounds)
Floors and walls cracks
Furniture Shake.
Liquid in open vessel are slightly disturbed.
Shock is noticeable in standing Cars.

ii

iii

V Awakening

i Felt by all
Many people awake
Few Run outside
Animals become uneasy.
Hanging objects - swing considerably
Pictures knocks and swing out of place
Pendulum Clock stops
Liquid Spills in small amount.
Unstable object overturn.
Door and windows open thrust.
Vibration- like heavy objects falling inside building.

ii Slight damage in Type-A-Building

iii Slight Waves on standing water.

VI Frightening

i Felt by most
Hanging items falls
Heavy furniture moves.

iii Cracks up to 100 mm width in wet ground
Landslip in mountains.
Change in flow of spring.

VII Damage of Buildings.

i Noticeable- difficult to stand
Large bells rings.

ii Landslide of roadway on steep slopes.
Cracks in roads.
Seams(Joint)- Pipeline damaged
Cracks in stone walls.

iii Waves formed in water
Water is turbid by mud stirred up.
Water levels in well change
Flow of spring changes
Dry springs restored their flow.
Existing Spring Stop flowing.
Sand and Gravelly bank slip off.

VIII Destruction of Buildings.

i Fright and panic
Also persons driving motorcycle disturbed.
Branches of trees breaks off.
Heavy furniture moves and partly overturn
Hanging lamp damaged.

ii Breaking of pipe line
Memorial and monuments move and twist.
Stone wall collapse

iii Small landslip in hollows
Banked road on steep slopes
Cracks in ground up to several cm.
Water is turbid by mud stirred up in lakes.
New reservoir comes into existence
Drywell refill
Existing well become dry.
Change in flow level of water.

IX General Damage of Buildings.

i General panic
Considerable damage to furniture
Animals run to and fro in confusion and cry.

ii Monuments and columns collapse
Considerable damage to reservoir
Underground pipes partly broken
Roadways damaged
Railway line bent up

iii On flat land overflow of water, sand & mud
Ground cracks widths up to 10 cm
On slope riverbank > 10cm crack
Fall of rocks
Landslide
Earth Flow

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Large waves in water.
Drywell refill
Existing well become dry.

X General Destruction of Buildings.

i -
ii Critical damage to Dykes and Dams
Severe damage to bridges
Railway line bent up
Underground pipes bent or broken.
Road paving and asphalt show waves.
iii Ground cracks widths up to several cm, up to 1m
Loose ground slides from steep slopes.
Coastal area- displacement of sand and mud.
Change of water levels in wells
Water from canals, lakes, rivers etc. thrown on land
New lakes occur.

XI Destruction

i -
ii Severe damage to well built buildings,
Bridges
Dams
Railway lines
Highway become useless
Underground pipes destroyed.
iii Ground-Distorted
Broad Cracks and fissures.
Numerous landslip and falls of rocks.

XII Landscape Changes

i
ii Practically all Structure above and below ground are greatly damage and destroyed

iii Ground surface radically changed
Ground cracks with vertical and horizontal movement
Falling of rocks
Slumping of river banks over large area.
Lakes are dammed
Waterfall appears
Rivers are deflected.

MAIN-REVISION IN NEW CODE

1 Bases of various load combination have been made consistant
2 Temporary structures are brought under the purview of this standard
3 Importance factor modified -Intermediate category and based on Density of occupancy
4 A provision introduced -All buildings are designed for at least min lateral forces
5 Building with flat slab are brought under the purvuew of this standard.
6 Additional clarity- regarding types of Irregularity
7 Effect of masonry infill walls included in analysis and design of frame buildings.
8 Method for approximate Natural periode- for building with basement, step back, Buildings in hill slopes
9 Providion on Torsion -simplified
10 Method for calculation of Liquiafaction potential analysis introduced

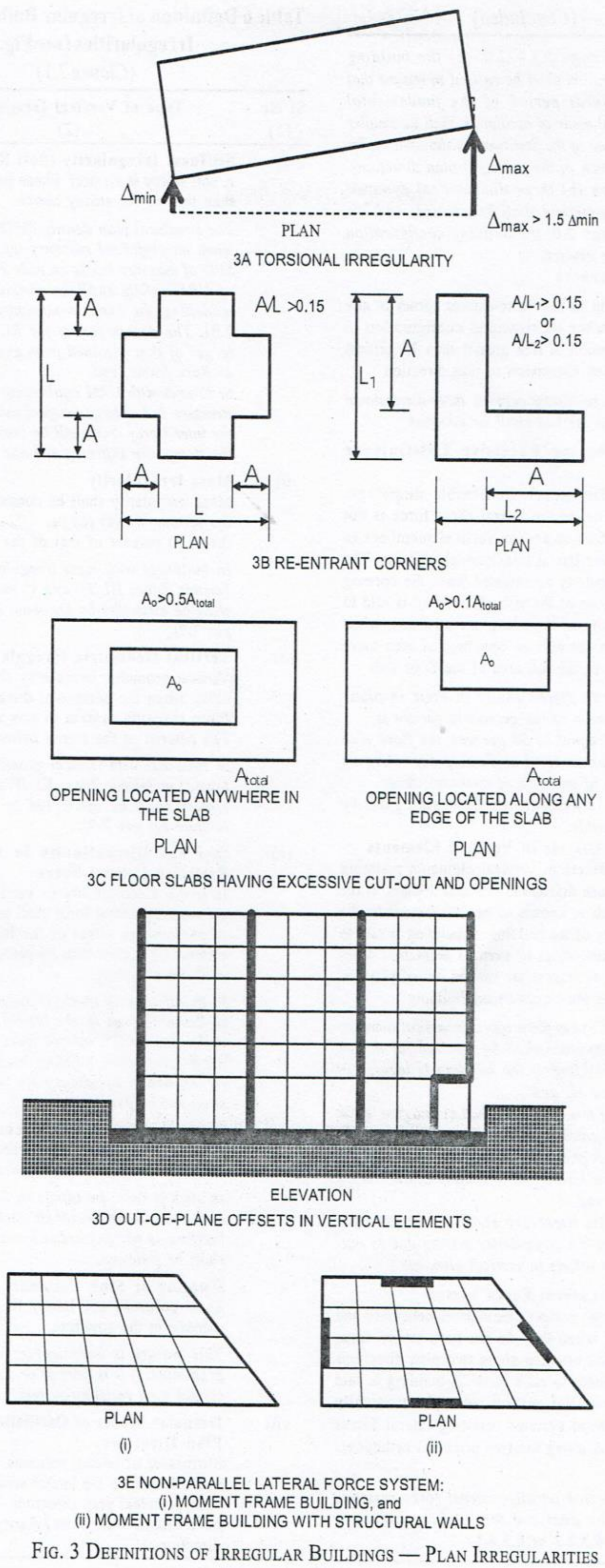
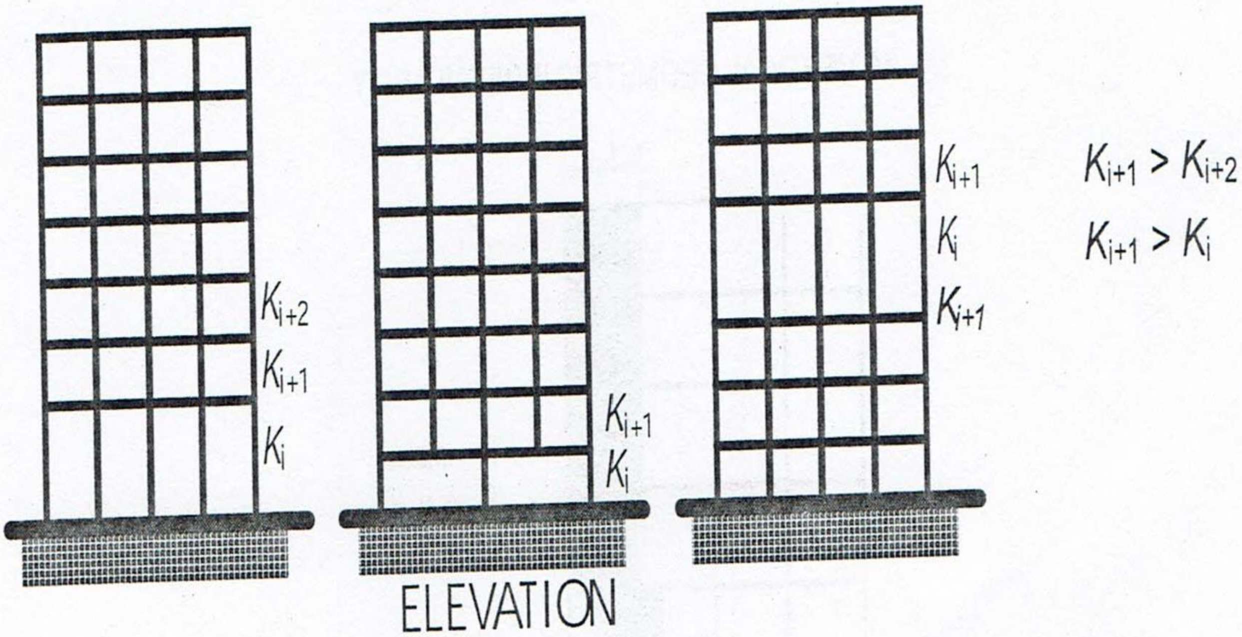
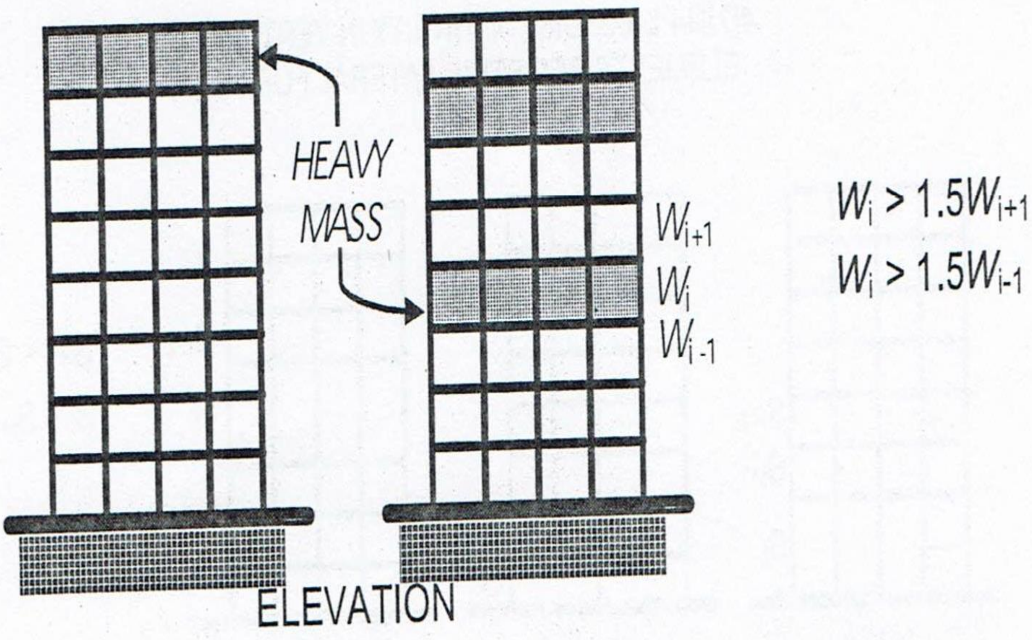


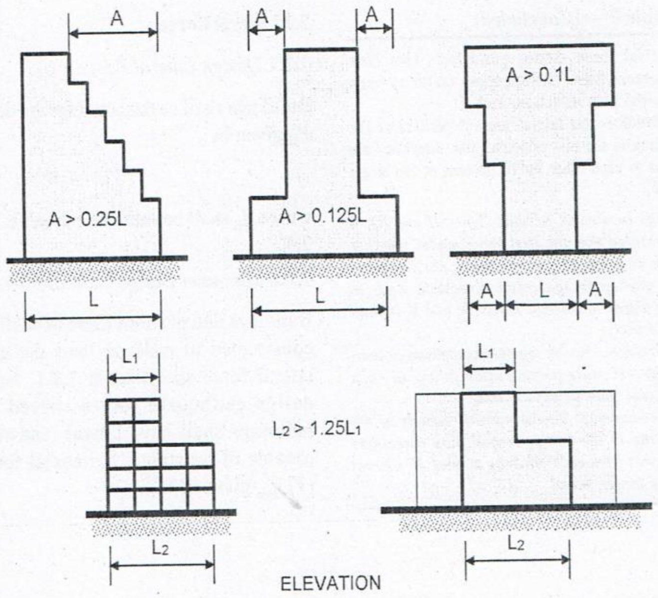
FIG. 3 DEFINITIONS OF IRREGULAR BUILDINGS — PLAN IRREGULARITIES



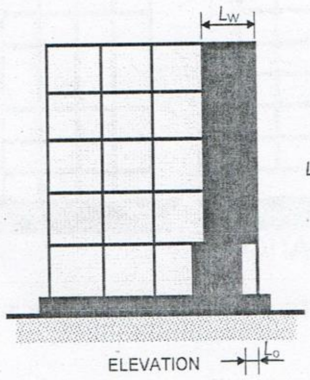
4A STIFFNESS IRREGULARITY (SOFT STOREY)



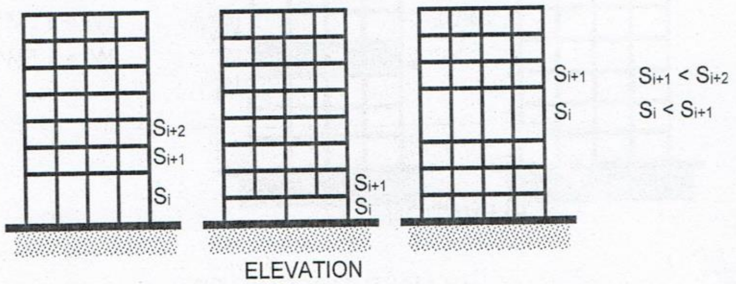
4B MASS IRREGULARITY



4C VERTICAL GEOMETRIC IRREGULARITY



4D IN-PLANE DISCONTINUITY IN VERTICAL ELEMENTS RESISTING LATERAL FORCE



4E STRENGTH IRREGULARITY (WEAK STOREY)

FIG. 4 DEFINITIONS OF IRREGULAR BUILDINGS — VERTICAL IRREGULARITIES

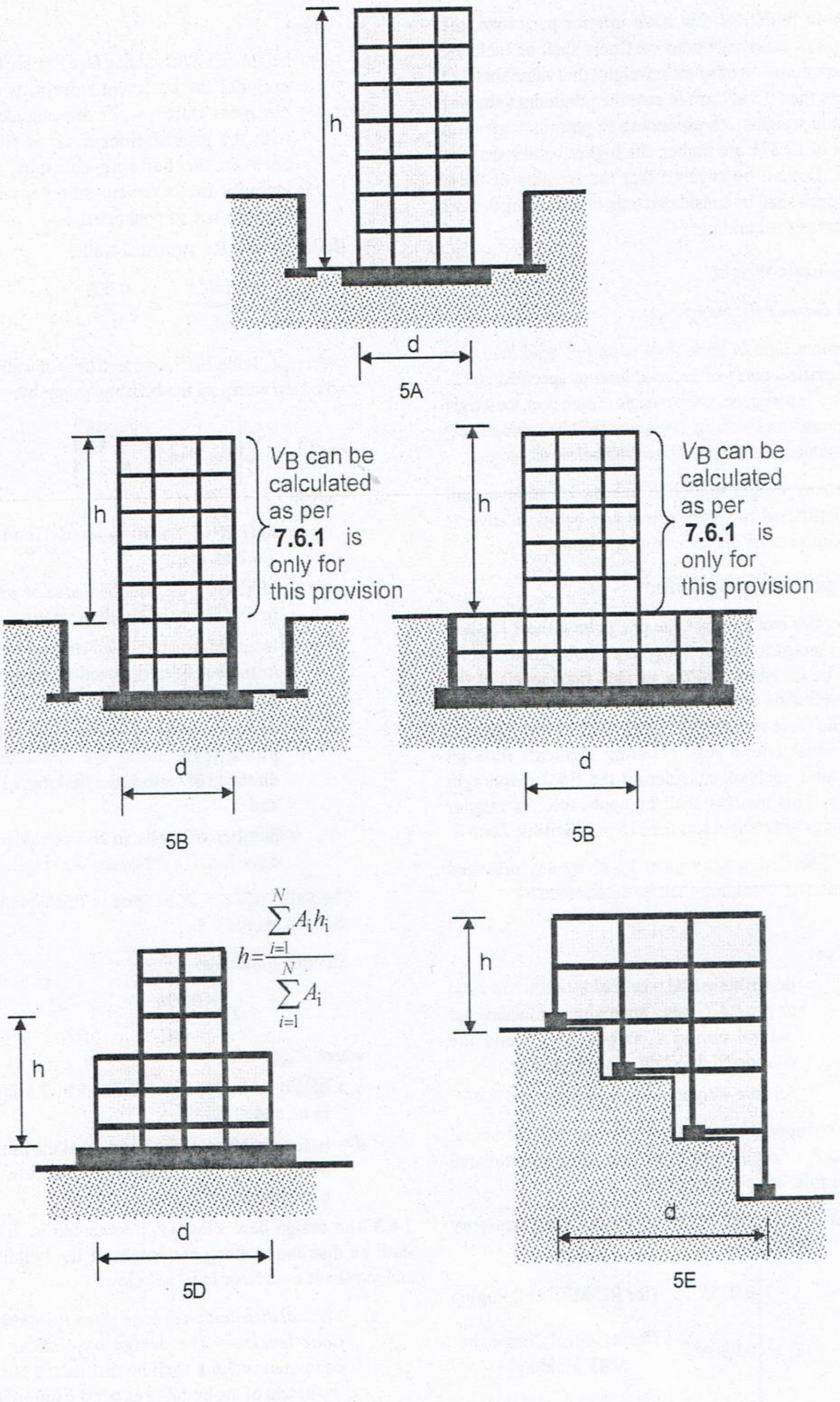


FIG. 5 DEFINITIONS OF HEIGHT AND BASE WIDTH OF BUILDINGS

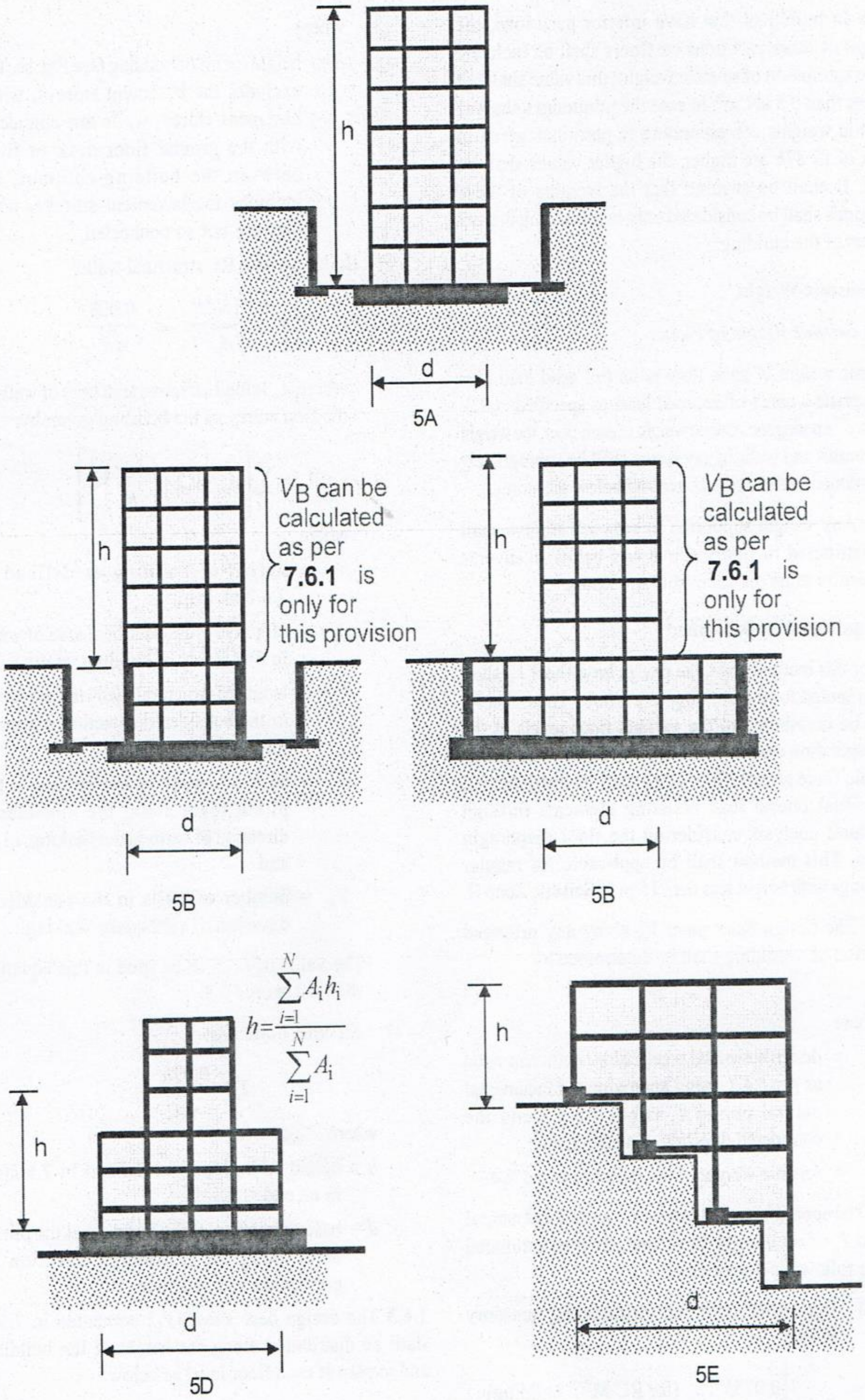


FIG. 5 DEFINITIONS OF HEIGHT AND BASE WIDTH OF BUILDINGS

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